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Fabrication of TiC Contacts on Carbon Nanotube Transistors

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Beamline(s): X20C

Introduction: Carbon nanotubes are quasi one-dimensional molecular structures with semiconducting or metallic properties that make them promising material for future electronic applications. One of the most interesting applications involves their use as channels in field-effect transistors. Early nanotube devices were fabricated by depositing single-wall carbon nanotubes on top of metal electrodes such as Pt or Au. These devices had generally high contact resistances and were unipolar with p-type characteristics (hole transport). Low contact resistance multi-wall carbon nanotube/TiC contacts have been made by Zang[1]. Presumably the low resistance is due to direct electrical contact of the metal with several layers of the nanotube. We have made successful carbon nanotube field-effect transistors (CNFETs) from end-bonded single-walled nanotubes (SWNTs) contacted to titanium carbide and passivated with a uniform SiO₂ layer[2].

Methods and Materials: Carbide contacted CNFETs were fabricated from a large array of devices made of 1.4 nm diameter s-SWNTs dispersed on a SiO₂ layer (150 nm thick) over a p⁺ Si substrate. Titanium contacts (50 nm thick) were formed by using optical lithography and standard lift-off techniques. The carbide formation was monitored by time-resolved X-ray diffraction using 0.180 nm radiation during annealing at 3 °C/s in helium ambient.

Results: Below 700 °C, a very intense XRD peak just below $2\theta = 44^\circ$ corresponding to the <0002> diffraction line of the hexagonal phase of the titanium film dominates the signal. A first transformation is observed just above 700 °C to form a titanium carbide (Ti_xC) phase with diffraction peaks at $\sim 41^\circ 2\theta$ and $\sim 50^\circ 2\theta$. Above 800 °C, one sees the transformation of the former phase and the appearance of two new intense peaks. The intensity stays constant up to 1100 °C. This reaction is the formation of the cubic TiC phase, with peaks at $40^\circ 2\theta$ (200 reflection) and $43^\circ 2\theta$ (111 reflection). Several CNFETs were subsequently prepared by quenching the substrate at 800 – 850 °C (after TiC formation), and capping them with a 10 nm SiO₂ layer deposited at room temperature and densified by annealing at 400 °C for 30 minutes in forming gas. The conductance for hole transport measured after the carbide reaction improved by more than two orders of magnitude. Transmission Electron Microscopy shows that Ti atoms have diffused to the core of the rope and a formed a TiC crystal.

Conclusions: By this method, the nanotubes in the bundles are end-bonded to the TiC crystal and the interface is abrupt. Most of the devices prepared show drastic improvement of the transconductance, from $\sim 1 \times 10^{-9}$ A/V before carbide formation to 2×10^{-7} A/V after formation. The gate was able to modulate the conductance by about 6 orders of magnitude.

References:

1. Y. Zhang, T. Ichiasahi, E. Landree, F. Nihey, and S. Iijimo, *Science* **285**, 1719 (1999).
2. R. Martel, V. Derycke, C. Lavoie, J. Appenzeller, K. Chan, J. Tersoff, Ph. Avouris, "Ambipolar Electrical Transport in Semiconducting Single-wall Carbon Nanotubes," *Phys. Rev. Lett.*, **87**, 256805 (2001).